CHARACTERIZATION OF THE THERMAL PERFORMANCE OF AN OUTDOOR TELECOMMUNICATION CABINET

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ABSTRACT

The growing use of telecommunication technologies has led the industry to develop infrastructure to support this progress. The outer telecommunications cabinets are part of the Base Transceiver Station (BTS) allowing to accommodate and protect from outer adverse conditions, a set of electronic equipment needed to operate the mobile communication network. This kind of cabinets should have a proper thermal performance to ensure indoor air temperature below 55°C to avoid exceeding the maximum operating temperature of the electronic equipment. This work describes the analysis of the thermal performance of an outdoor telecommunication cabinet (OTC) using the computational tool DesignBuilder. The simulation results are compared to the experimental data collected in real cabinet under normal operating conditions. The simulation results show that the air temperature predicted by the model is closer to the temperature measured experimentally inside the cabinet particularly when the weather data files of the computational model have a similar behavior to the actual weather data. Numerical studies show that the use of mechanical ventilation is effective in the extraction of heat generated inside the cabinet. However, there is a limit beyond which increasing the air flow rate does not result in a significant decrease of the cabinet air temperature. The studies also show the importance of the radiant properties and the geographical location of the cabinet. High values of the outer surface cabinet emissivity impair the thermal performance of the cabinet during the day and for some locations, an operational mechanical ventilation system may not be enough to maintain the indoor air temperature below 55°C. Overall, the use of DesignBuilder proved to be very effective for characterizing the thermal performance of telecommunications outdoor cabinets.

Keywords: DesignBuilder, numerical modeling, telecommunication outdoor cabinet, thermal characterization.

1 INTRODUCTION

The increasing technological development and globalization had a significant and direct impact on our way of living. Communication technologies particularly improved the communication between people and between companies, their mobility and carrying out everyday tasks that otherwise would require more time and resources to be achieved. A typical wireless telecommunications network makes connections between different terminals, allowing the exchange of information between them. The basic infrastructure of a telecommunications network is the BTS, which could present energy consumption greater than other public buildings [1]. In that way, if the telecommunications industry wants to save economic resources and become more sustainable, it is imperative to reduce the energy consumption of BTS [2]. Cooling demand of a BTS can represent up to 25% of its energy consumption; therefore, implementing less energy consumption cooling techniques has a good energy saving potential [2, 3]. An important component of the BTS is the outdoor telecommunication cabinet (OTC), which contain several electronic equipment that require a correct thermal management. Some of that equipment may become inoperable if temperatures higher than 70°C occur inside the cabinet [4, 5]. So, a proper management of the air temperature inside the OTC brings, not only, energy advantages but it is also essential for a good performance, reliability and durability of electronic equipment [6]. More than half of the failures in elec-

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tronic systems occur due to poor temperature control [7]. The results of experimental tests on electronic components indicate that decreasing 1°C on its surface temperature reduces the probability of failure in 4%. Additionally, the increase between 10°C and 20°C in the surface temperature increases component failure probability in 100% [8]. The temperature increase may additionally accelerate chemical reactions, increase corrosion and induce redox reactions in some metals. It can also increase the accumulated fatigue of welded components, or cause frequency changes of the internal clocks of the processors, which can lead to undesirable time gaps [9–11].

When natural convection cooling is insufficient to maintain the ideal conditions for equipment operation, it is necessary to apply other cooling techniques. In that case, forced ventilation emerges as one of the most widespread techniques for equipment cooling, due to the low cost of implementation and simplicity [12, 13].

However, the use of forced ventilation with outside air presents some drawbacks, due to dust and moisture transport to the interior of the OTC. Moreover, because the filters are not designed to maintain their function during the lifetime of the OTC, it is necessary to perform maintenance procedure that leads to an increase in its maintenance costs [3]. When cooling by forced ventilation is not enough to remove the heat inside the OTC, other cooling techniques may be used, such as vapor compression refrigeration. However, the power consumption associated with this type of solution may correspond to about 30–50% of the total energy consumed in the BTS [14].

In addition to these conventional solutions, there is also the possibility to choose other cooling techniques, active and passive, including the thermoelectric cooling, geothermal cooling or the use of phase change materials (PCM), among others [12, 15, 16].

In the present paper, a numerical model of an OTC was prepared using the computational tool DesignBuilder. The results of the computer model were compared to experimental data collected in a real cabinet in normal operating conditions. Subsequently, the computer model was used to characterize the thermal behavior of the cabinet submitted to different operation conditions, internal or external.

2 MATERIALS AND METHODS

DesignBuilder, version 3.4.041 – with Energy Plus 8.1, was the computational model used in this simulation study. The DesignBuilder emerged in 2005 as the first, and currently the most complete, graphical user interface with the EnergyPlus. This computational tool has the ability to simulate the thermal behavior of a building in a variable time base, as well to calculate the energy consumption, in order to test solutions and strategies to improve energy efficiency. For this, it is necessary to introduce in the program a variety of parameters, such as the location, the geometry, the parameters related to activity, the lighting, the constructive elements, the glazed surfaces, the HVAC systems, among others [17]. Additionally, this tool includes solar radiation effects, which may represent an important thermal load with consequences on the indoor air temperature value and, consequently, on the OTC equipment reliability.

2.1 Outdoor cabinet description

The experimental data were collected from an OTC located near the city of Covilhã, in the inland/center region of Portugal. The OTC location is subject to sunlight for most of the day. The cabinet consists of a pedestal, an intermediate space that houses the telecommunica-

Figure 1: Exploded view of the outdoor telecommunications cabinet.

tions equipment and switchboards and, finally, an upper space where the fans are installed. In Fig. 1, it is possible to easily distinguish the different constituent parts of the cabinet, through the exploded view. The pedestal is 150 mm high and has lateral openings to facilitate the passage of cables. The side panels are removable, improving access to the interior. The outer dimensions of the OTC are 638 × 644 × 1,480 mm^3 (Length × Width × Height). However, the useful inner dimensions for the placement of equipment are only 483 × 550 × 1,111 mm^3. The construction material is an alloy with 55.0% aluminum, 43.4% zinc and 1.6% silicon. The alloy is used in sheets with 1 mm thick. All panels have double walls with an air enclosure with 20 mm thick, in order to reduce the thermal load by solar radiation absorption. The ventilation of the air enclosure in each panel is achieved through two grilles placed in the exterior sheet for air flow, one at the bottom of the cabinet, for air inlet, and the other located in the upper part of the cabinet, for air outlet. It is also through the bottom grilles that the air flows into the cabinet.

The OTC is painted with light color to reduce heat gain from solar radiation.

2.2 Cabinet characteristics

The telecommunication equipment that is installed inside an OTC depends on the telecommunications company that operates the BTS and on the services it intends to provide. The temperature control system, lighting, door-opening sensor and electrical switchboards are already installed with the cabinet. Since the communications equipment installed in each cabinet depend on the company that operates the network, its spatial arrangement may vary from case to case. For the studied case, the devices installed in the OTC are identified in Table 1. This information results from technical information provided by the equipment manufacturer. Some of this equipment has negligible thermal power dissipation.

Table 1: Equipment installed inside the cabinet under study.

Equipment	Function	Thermal power dissipated (maximum value)
AC Switch board	AC energy supply	Negligible
DC Switch board	DC energy supply	Negligible
BBU3900 Huawei	Baseband control unit	295 W
Alcatel-Lucent 7705	Router	60 W
EMILO-SNT - PT Inovação	Modular system type *Multi-Service Provisioning Platform* (MSPP)	120 W

Overall, the equipment that was considered inside the OTC has a heat output potential of 475 W. However, this scenario only occurs when all the equipment is dissipating the maximum thermal power for which they were designed. The value is lower in typical operating situation. The studied OTC is located in a low population density region. In fact, it was installed to provide mobile network coverage to a highway, thus it is expected a thermal power dissipation values considerably below 475 W.

2.3 Cabinet thermal control

The OTC temperature control system should have the capability to allow monitoring the temperature and increase the heat extraction rate, if necessary. According to the OTC supplier company, with a maximum thermal power dissipated by the electronic equipment lower than 250 W, the natural convection cooling mode is enough to ensure an inside air temperature below 50°C.

However, the cabinet under study is equipped with a forced cooling system that is triggered whenever natural convection alone is not able to ensure the indoor air temperature. The cooling system consists of two axial fans that are activated by a thermostatic sensor, a type on/off system. Both fans work together and are always operated as the indoor air temperature is higher than 35°C. The main operating characteristics of fans are shown in Table 2.

There are several constraints on the fluid flow inside the OTC, such as equipment and wiring, orifices diameter of the inlet and outlet grilles, the obstructive effect caused by the air filters and an existing perforated plate to protect the fans. In addition, inadequate maintenance of the OTC and subsequent accumulation of dust in the filter along the operating time also contributes to a reduction of the air flow. As result of the pressure drop associated with the air flow through the OTC, the actual air flow should be substantially lower than the value shown in Table 2.

Table 2: Cabinet fans characteristics.

Nominal voltage	48 V
Electric power input	5.1 W
Operation temperature range	–20°C to 75°C
Nominal air flow	170 m^3/h

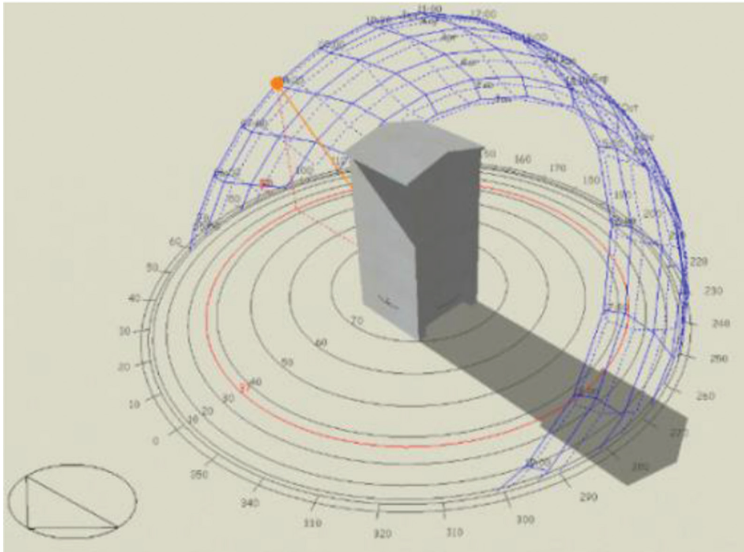

Figure 2: Outdoor cabinet modeled with DesignBuilder.

2.4 Computational model

For simulation purposes, the three-dimensional numerical model with real OTC dimensions was built using the DesignBuilder, as displayed in Fig. 2. The computational model consists of six Blocks corresponding to a zone having an internal volume 0.46 m^3 and an HVAC system to simulate the real ventilation system provided by the fans in the OTC. The backside panels and the front door have double wall thickness of 20 mm as in the actual OTC. As the program does not have the alloy used in the construction of the OTC their thermal characteristics were manually added: thermal conductivity 160 W/mK, specific heat 880 J/kgK and density of 2,800 kg/m^3. To simulate thermal loads within each zone, DesignBuilder has several options according to their source. The Lighting submenu was used to overcome the 60 W/m^2 limitation of the thermal load value imposed by the program in the submenu Activity.

The submenu Lighting allows the introduction of the thermal dissipation rate inside the cabinet per unit of area without restrictions. The area used in the calculation of the thermal load inside the cabinet is 1.43 m^2 corresponding to the sum of the floor area in each one of the blocks involved in numerical simulation. Additional details of the computational model can be found in [18].

3 ANALYSIS AND DISCUSSION OF RESULTS

In this section, the results obtained from the computer model are analyzed and discussed. The simulation values and the experimental values are compared in the first subsection to validate the computational model. After that, parametric studies with the computational model are developed to assess the influence of various factors such as the volumetric air flow, thermal power dissipation, radiant properties of the cabinet envelope and the OTC geographical location.

3.1. Comparison with experimental data

The computational model was validated by comparison of the numerical results with experimental data obtained from an OTC in normal operation. As said before, the cabinet chosen to collect experimental data is located in the municipality of Covilhã, close to the A23 highway. The cabinet experimental values were collected between 15 and 19 April 2015, and it was considered an average thermal power of 100 W dissipated by the electronic equipment due to the low use of the OTC in the period. The values of the cabinet indoor temperature obtained experimentally are crossed with numerical values for the same period. However, the climatic data files used in this kind of simulation software influence significantly the quality of results [19–21]. Thus, the climatic data file used in Design Builder was compared with values measured at a weather station near to the OTC in the same period. The weather station provides a set of climatic data including air temperature, wind speed and solar radiation. The comparison between the weather station data and the DesignBuilder climatic data is shown on Figs s3 and 4 to the values of the outdoor temperature and the solar radiation in the period.

From the analysis of F Figs 3 and 4, it appears that the 16 and 17 April show the best agreement of solar radiation values and air temperature for the period.

The temperature values inside the OTC for the same period are shown in Fig. 5. According to Fig. 5, when the actual weather data and the weather data from the computational model have a similar behavior, also the air temperature inside the OTC predicted by the model is closer to the temperature measured experimentally. This figure also allows concluding that the OTC fans are never actuated during the period, since the indoor air temperature never exceeds 35°C.

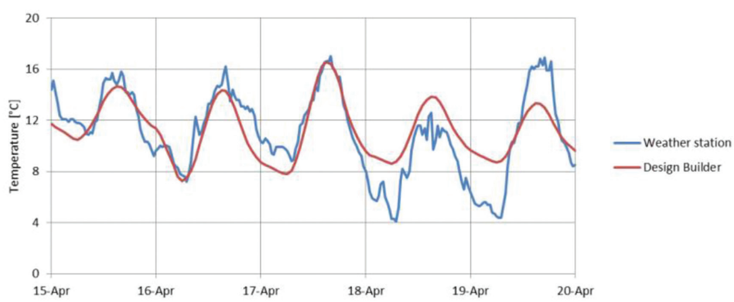

Figure 3: Outside temperature (weather station vs. DB climatic data file).

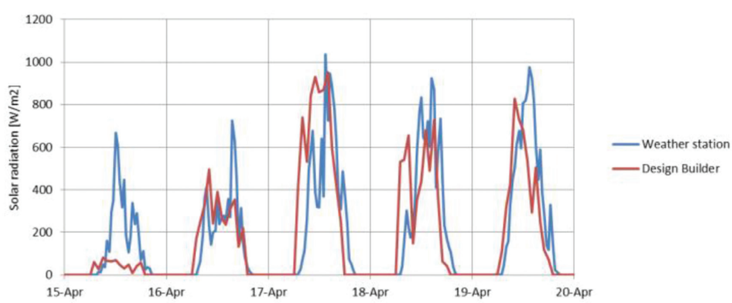

Figure 4: Solar radiation (weather station vs. DB climatic data file).

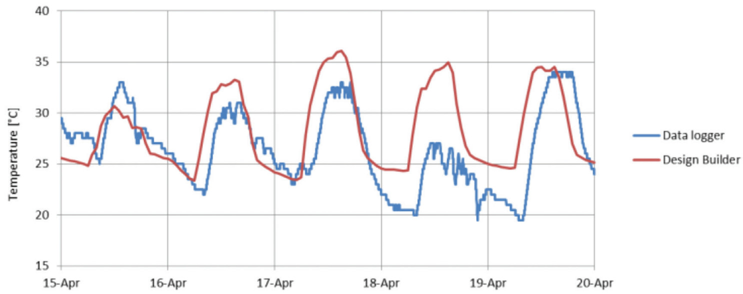

Figure 5: Temperature values inside the cabinet, numerical and experimental.

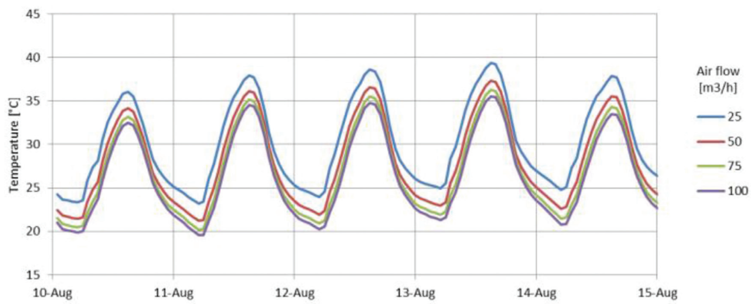

Figure 6: Inside air temperature vs. cabinet air flow rate.

3.2. Parametric studies

The computational studies presented in this subsection are directed to the most demanding situation from the thermal point of view, corresponding to the summer period in northern hemisphere. The period between 10 and 15 August was selected since the highest values of the air temperature inside the cabinet are expected.

3.2.1 Air flow rate

When the OTC thermal dissipation rate is not high enough to keep the inside air temperature with acceptable values, it is necessary to resort to forced ventilation. The characteristics of the flow provided by the fans influence the amount of heat that is withdrawn from the OTC to the outside per unit of time. The effect of the volumetric air flow that passes through the OTC on the inner air temperature is shown in Fig. 6. The maximum measured air temperature difference in the period is around 3–5°C to the minimum and maximum air flow rates studied, 25 m^3/h and 100 m^3/h, respectively. It is necessary to quadruple the air flow rate for an air temperature decreasing of around 4°C. The decrease of the air temperature inside the OTC is more pronounced when the air flow rate ranges from 25 m^3/h to 50 m^3/h. From this value, the decrease of air temperature is smaller. An air flow rate increase from 75 m^3/h to 100 m^3/h results in an air temperature decrease of only 2%. Thus, the optimization of the thermal performance of an OTC cooled exclusively by forced air circulation requires appropriate volumetric air flow rates.

3.2.2 Thermal power dissipated

The thermal power dissipated by the electronic equipment inside the OTC is one of the most relevant factors to the variation of the inner air temperature. The air temperature inside the OTC to average thermal power dissipated ranges between 100 W and 400 W are shown in Fig. 7. These results were obtained considering that there is no renewal of the air inside the OTC and reveal an almost direct proportionality between the air temperature and the thermal power dissipated, as shown in Fig. 7. However, an air temperature inside the OTC below 55°C without forced ventilation only is assured for a dissipated thermal power lower than 100 W. Therefore, an operational mechanical ventilation system is required for higher dissipation rates. The evolution of the air temperature inside the OTC due to thermal power dissipated for an air flow of 100 m^3/h is shown in Fig. 8.

The air temperature inside the cabinet increases with the thermal power dissipated. However, the inside air temperature slightly exceeds the threshold value of 55°C for safe operation of the cabinet only for the situation with thermal power of 1,000 W and only for the 13th of August. When the dissipated thermal power was set at 800 W, the maximum air temperature attained inside the cabinet for the period studied was 50°C. It is found that for thermal power dissipated values between 100 W and 700 W, the maximum air temperature inside the OTC increased by about 4°C every 200 W of increase in the value of the dissipated thermal power.

3.2.3 Radiative properties

As the OTC are in general exposed to the action of solar radiation, radiative properties of the OTC envelope affect the air temperature inside the cabinet. In practice, these radiant properties can be modified by changing the OTC building materials or outer coating.

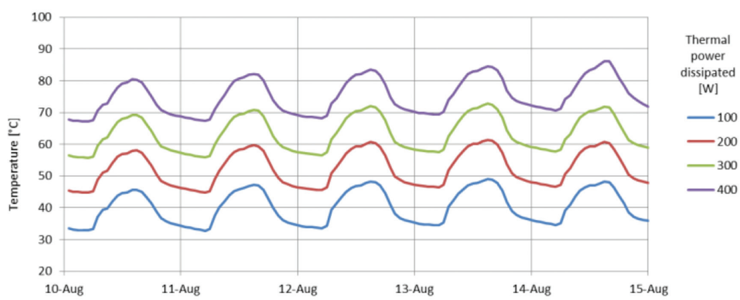

Figure 7: Inside air temperature vs. thermal power dissipated (no ventilation).

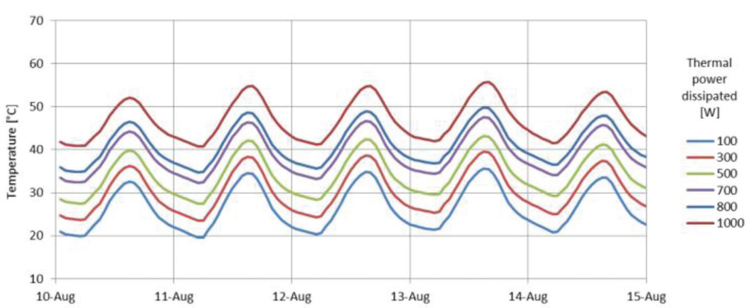

Figure 8: Inside air temperature vs. thermal power dissipated (with ventilation).

Figure 9 shows the evolution of air temperature inside the OTC by changing the emissivity values of the outer surface of the cabinet. The results show that the OTC radiant properties affect the air temperature during diurnal periods when the cabinet is exposed to solar radiation, with higher air temperature values to higher surface emissivity values. With an emissivity value of 0.95, the air temperature inside the cabinet exceeds 55°C during the period, whereas with 0.1 emissivity value, the air temperature inside the OTC always remains below 45°C.

It can be concluded that high emissivity values of the outer surface impair the thermal performance of the cabinet during the day, which can jeopardize an effective air temperature control. During the night period, the variation in emissivity values has little influence on air temperature.

3.2.4 Other geographic locations

To study the effect of the geographical location in the OTC thermal response some cities located in the northern hemisphere were selected (see Fig. 10) in order to keep the period of study between 10 and 14 August.

The climatic data for the new locations were obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC POWER Project [22]. According to Fig. 10, the city of Ostersund (Sweden), in Northern Europe, has the lowest air temperature values inside the OTC, thus enabling greater thermal power dissipated compared to the other cases studied. For hot climates, such in Riyadh (Saudi Arabia), even for a thermal power dissipated

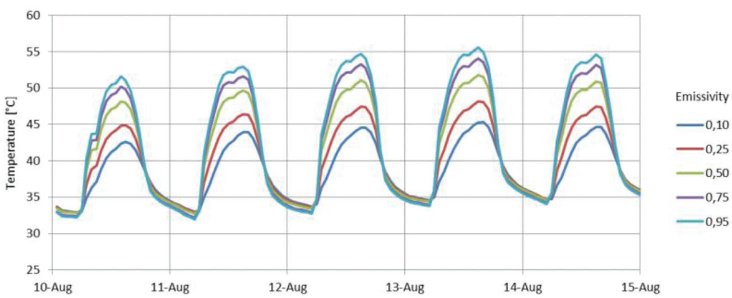

Figure 9: Temperature values inside the cabinet for several emissivity values.

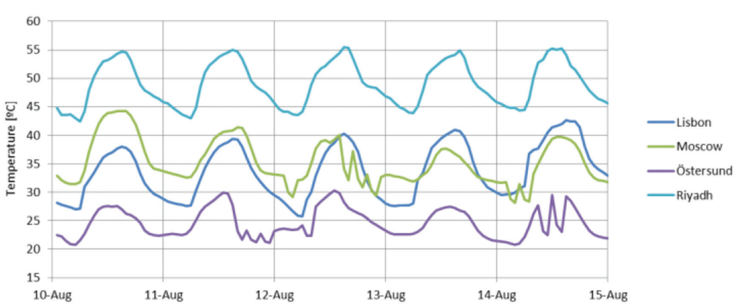

Figure 10: Inside air temperature for other OTC geographic locations.

of 100 W, the air temperature inside the cabinet is above 50°C in most part of the daytime and sometimes exceeding 55°C. For these situations, an operational mechanical ventilation system may not be enough to ensure the safe operation of the OTC. Lisbon (Portugal) and Moscow (Russia) showed similar results with maximum air temperature values below 45°C, and therefore the natural ventilation is adequate for low thermal power dissipated by the electronic equipment.

4 CONCLUSION

In this study, the computer simulation of the thermal performance of an OTC was performed using DesignBuilder. Overall, the use of DesignBuilder proved to be very effective for characterizing the thermal performance of OTC. The simulation results show that when the actual weather data and the computational model weather data files have a similar behavior, the air temperature predicted by the model is closer to the air temperature measured experimentally. The studies carried out show that the maximum temperature difference of the air inside the cabinet for air flow rates ranging from 25 m^3/h and 100 m^3/h, is between 3°C and 5°C. However, for higher airflow rates, the air temperature reduction is lower, and therefore, the increase of the air flow rate while contributing to the increase of energy consumption of the OTC not always provides a maximum control of inside air temperature. Research undertaken also shows a direct relationship between the increase of the thermal power dissipated by the electronic equipment inside the cabinet and the maximum temperature of indoor air. It was found that the temperature of the air inside the cabinet only remains below 55°C to dissipated thermal power lower than 100 W. For higher values, it is necessary to resort to the mechanical ventilation of the OTC. The simulation results also show that high values of the cabinet outer surface emissivity impair the thermal performance of the OTC during the day and may jeopardize the temperature control. The geographical location also influences the thermal performance of the OTC. The results show that for some locations an operational mechanical ventilation system may not be enough to ensure the safe operation of the electronic equipment inside the OTC.

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